Energy
Technology
Futures

Results from the Biotechnology Focus Group

# Draft #2

Held on November 20th, 1998
Plant Biotechnology Institute, NRC
Saskatoon, Saskatchewan
Compiled By Paul Khanna, 01/11/99

## Disclaimer

This document represents the first draft using information from the November 20th focus group and the McLeod Institute Report on Biotechnologies. This document may contain errors and inaccuracies that will be amended in the final draft. Please direct corrections and comments to Paul Khanna at (613) 943-9216 or email pkhanna@nrcan.gc.ca.

## Introduction

The Energy Technology Futures Group organized a Focus Group on Biotechnology on November 20th, 1998 to reinforce and expand on our existing information and understanding. It also served to bring together a diverse group of people in the field of biotechnology covering many aspects of this broad science. The conference was held at the Plant Biotechnology Institute, a part of the National Research Council, in Saskatoon, Saskatchewan.

## Background

### Mission Statement

The session started at 8:30 AM and went on to 4:30 PM. We began with a presentation of the Energy Technology Futures project and a mission statement for the day. The charge to the group was to:

- Brainstorm possible biotechnology processes and systems for Canada in the period 2030 to 2050
- Identify key technologies that Canadians could be using in that period
- Identify R&D priorities for the area, and critical paths, technology gaps, and barriers to implementation

This was followed by three short presentations on biotechnology in the 2030-2050 time frame by three of the participants and a clarification session of the day's objectives. Then the group broke up into teams for the rest of the day to complete the day's assignment and periodically report back to the group as a whole. In the last hour a roundtable discussion transpired concerning the ETF process and the role of the federal government in the field of biotechnology

**Contributors**
The focus group had eleven outside attendees. They included contributors from industry, government, and academia. The list of attendance is as follows:

1. **Ajay Dalai**, Department of Chemical Engineering, University of Saskatchewan
2. **Malcolm Devine**, Manager, AgrEvo Canada Inc.
3. **Murray Gray**, Department of Chemical and Materials Engineering, University of Alberta
4. **Wilf Keller**, Group Leader of Brassica Biotechnology, Plant Biotechnology Institute
5. **Peter Lau**, Senior Research Officer, Biotechnology Research Institute
6. **Jim MacPherson**, Senior Scientist, Performance Plants Inc.
7. **Dave Minns**, Director, Institute for Chemical Process and Environmental Technology
8. **Louise Nelson**, Manager, Ag Biologicals, Agrium Inc.
9. **Hans Peterson**, President, WateResearch Corp., Algal Applications
10. **Martin Reaney**, Agriculture and Agrifood Canada
11. **Gopalan Selvaraj**, Group Leader of Promoter Technology, Plant Biotechnology Institute

Also present were three members from the Energy Technology Futures office.

**Kevin Cliffe**, Director of Energy Technology Futures.
**Glen Milne**, Facilitator of the focus group.
**Paul Khanna**, Technology Advisor, Energy Technology Futures and group organizer.

**Notes on the Report**
The results from the focus group have been rearranged into a readable report outlining the state of biotechnology, what tools will we have and how will we use them, the impacts on Energy technologies and how Canada can meet future challenges. Extra details have been added for clarity and drawing conclusions. Also, references have been made to the Technology Fact Sheets (TFS) from the McLeod Institute based at the University of Calgary. A glossary of terms is located at the end of this report for reference purposes.

## State of Biotechnology and its Roles Future Energy Technology

Biotechnology is becoming a significant shaping force in our lives. The breadth and power of biotechnology solutions and processes will change the technological landscape in fantastic ways. We are moving asymptotically towards perfect knowledge giving us near total control. We are, and need to continue, moving by quantum leaps as well as incremental steps. If we utilize these technologies correctly Canada, and the world, will reap tremendous benefits. This is especially true when it comes to climate change mitigation technologies.

The goal is to make and save energy and reduce green house gas emissions by developing and harnessing living systems through the management of genetic information. Biotechnology's reliance on living organisms gives it an advantage. By their nature, organisms manage their incoming and stored energy more efficiently than industrial systems and their waste products are useful to other forms of life. As the use of this technology permeates through the economy the term 'waste product' may be replaced with 'low energy yielding product'.

There are opportunities for biologically derived fuels, materials and products. Processes may be easily transferable to large and small applications

Biochemical processes could replace many chemical and industrial processes. Biotechnology could redefine methods for:

- Contaminant removal
- Materials separation
- Dehumidification
- Liquification
- Fractional distillation
- Electrolysis
- Electro-synthesis
- Chemical synthesis processes like the Sabatier process, Ostwald process (ammonia and oxygen forming nitrous acid and nitric oxide), and the Raschig synthesis (Ammonia and the hypochlorite ion forming hydrazine and water).

## Tools of the Trade

This section outlines the methods that will be expanded upon in the future for use in the 2030 to 2050 time frame.

### Genomics

The gene is the element that specifies a sequence of amino acids to make a polypeptide chain and, in turn, a protein. By the middle of the next century we will most likely have discovered all the functions of gene blocks for most organisms and be able to build artificial chromosomes to organize DNA. Gene sequencing will have identified sets and assigned functions. Metabolic pathways and developmental processes will probably be understood for the majority of organisms.

### Genetic Engineering

Genetic engineering, in its broadest terms, is the procedure for isolation, manipulation, and expression of genetic material. This involves the targeting of genes and multiple genes for specific properties and transferring them to other organisms. Also, the inserted genes in the host organism need to be controlled and regulated.

A high level of genetic engineering knowledge will lead to full gene design and protein engineering. This control of metabolism and development will allow production of customized life forms producing stable enzymes for varied usage.

### Hybrid Microbes and GEM's

A common problem with microbes and enzymes is the restrictive nature of the environment needed for them to maintain viability. Hybrid microbes and genetically engineered microorganisms (GEM) are a solution to this problem. Through genetic engineering (recombinant gene splicing) and selective breeding we can combine and refine microbes for an array of tasks. Certain organisms can survive in extreme conditions such as below the freezing point of water or above the boiling point, in high radioactivity, in high salinity, in extreme dehydration, or under high pressure. Also, useful and unique genetic traits can be found in a wide variety of wild type microbes as well. Enhancing existing adaptations of extremophilic or unique microbes or their enzymes (biological catalysts) and adding that genetic code into other organisms will create life for intense and singular environments. As recombinant DNA technologies are refined and knowledge continues to grow, one could perhaps take a common organism and re-engineer it for desired traits in a matter of days.

### Plant-Microbe Interactions

Microorganisms and plants have many mutually beneficial associations, for example, there is the symbiotic relationship between nitrogen fixing bacteria and leguminous plants. Through more research we will have a better understanding of relationships between plants and microbes. This knowledge could allow us to enhance existing associations and create new associations with genetically engineered bacteria and/or plants.

**Propagation**
Developments in the ease of propagation will allow for faster and more efficient creation, dispersion, and establishment of seeds and propagules. This could make it easier to plant vast areas with genetically altered seedlings. This would increase the speed that genetically altered organisms can be distributed in the environment and quicken innovation and progress in plant biotechnology.

**Bioinformatics**
As knowledge in the biological area grows, computers have an even more significant role to play. The fields of biology and computer technology are beginning to intertwine. There are two sides to this, the effect of computer technology on biotechnology and vice versa. The effects of computer technology on biotechnology are improved databases, better modeling tools, three dimensional gene manipulation. The effect of biotechnology on computer science is DNA based processing and memory units.

Computer influences on biotechnology will mean large genomic libraries available for reference. Gene design through three dimensional and virtual reality technology will be essential tools. Also, experiments could be done in silico as well as in vitro or in vivo. This would allow for a more rapid creation of GEM's and speed development time to a particular end use organism.

Biological computers involve the use of DNA sequencing in conjunction with linear computing technology to provide a faster and more efficient information storage and retrieval system. This field will co-evolve with the understanding of genes and genetic products. The result will be revolutionary new chips that have superior speed and storage capabilities working in tandem with existing computer technology.

Also, biological/computer interfaces will be needed and there could be a whole new array of smart and intelligent products that use biological controls and sensors to trigger biological or mechanical responses. This may mean an artificial olfactory sense being used detect harmful gases and triggering a mitigating response.

**Supercritical Fluids**
For different gases there is a point above a certain temperature where the gas will not change to liquid phase with increased pressure. It moves into a supercritical phase, which is a coexistence of gas and liquid, with properties of each. Enzymatic compounds can be used with solvents as reaction mediums in industrial processes. The fluid protects the enzyme from microbial contamination and can allow the enzyme to exhibit novel properties such as altered specificity, the ability to catalyze new reactions, and enhanced thermostability. In supercritical fluids, pressure can be used to adjust the synthesis different monomers and polymers.

**Technology Linkages**
All of these tools in different combinations can allow improvement in areas such as genetic engineering, artificial intelligence, neural net technology, nanotechnology, robotics with biosensors, smart and intelligent systems, and bioremediation.

## Applications in the 2030 – 2050 Era

**Industrial Processes**
Biotechnology can give many advantages to industrial methodologies. Solutions can be assimilated into many steps and processes. Microbial products of industrial interest are:

- The microbe itself (yeast, nitrogen fixing bacteria)
- Enzymes (starch digesting amylases, other biocatalysts)
- Primary and Secondary Metabolites (ethanol and acid production)

Biochemically derived energy can used to drive processes and enzymatic catalysts can speed processing and treatment. As biological systems replace chemical systems there will be much more fine control over production and there could be a significant drop in waste gas production. Microbial ecologies will give us more integrated bioprocessing units, which will reduce the number of stages required to final products. Natural dampening reflexes of different organisms in a changing environment can allow for complex chemical creation in just one or two vessels.

Two of the main advantages of enzyme usage are that they yield fewer by-products during processing (a trait called specificity) and can start with less purified materials (selectivity). Currently, their use may be costly and require large amounts of water. But, it probably will not always be this way. Technologies like supercritical fluids as a media for enzyme reactions can improve versatility. (For more information see TFS A-8.)

In 50 years, off the shelf microorganisms could be available for bio-bleaching and mineral bio-oxidation. Thermophilic bacteria to leach metals like copper and gold from sulphide material could be used in hard to reach places or where amounts are small. Such methods are advantageous due to:

- Potentially large energy and green house gas savings
- Their shorter setup and dismantling time.
- Minimal and non-toxic effluents.
- Excellent metal recovery.
- Viability at ambient temperatures and pressures.

These traits make these processes applicable to small projects or other projects once thought not economically viable.

In the pulp and paper industry there are many niches for biotechnology beyond forest sustainability (see Green House Gas Storage). In processing wood fibre to make paper, the cellulose fibres must be separated from the lignin. Bio-pulping involves lignin-degrading fungi to carry out this process. Also, cellulose-decomposing enzymes such as cellulase and hemicellulase can be used to partly break down the cellulose in paper. This can make each sheet more porous and accelerate draining to speed the process. Enzymes with chemicals can reduce the energy and chemicals required in chlorinating. This does not necessarily mean that the whole process is carried out this way, it could be only a

fraction, for example, but that would still represents significant energy/cost savings while reserving the heavy chemical processes for 'polishing' only. In the pulp and paper industry, applications can be found that aid mechanical processes or make them obsolete.

Biotechnology could have many niche applications in industrial processes. It can be used to enhance existing processes or replace them entirely. It can also be used to develop more portable and small scale processing solutions.

**Agriculture**

From a biological standpoint, all farming and fishing can be conceived as a form of mining. Ways of conserving certain minerals in the soils and oceans will help lead to a more sustainable agricultural economy. Developing crops that are self-fertilizing and create their own multiple defenses such as herbicides pesticides would be very helpful. Metabolic manipulation may allow for crude mineral fertilization techniques that would be less volatile than liquid or gaseous fertilizers in the surrounding environment. Nitrogen fixation by all crops would make fertilization much easier. Perhaps it is best to improve yields in existing optimum conditions as opposed to improving fringe performance. (For more information see TFS A-2 and A-4.)

Better use of food wastes would also help the fuel industry. Crude wastes can serve as raw materials for fermentation in ethanol creation or industrial acid production. Also, more fermentation derived preservatives would decrease energy consumption in refrigeration.

With respect to livestock raising, there are many ways to reduce the amount of feed necessary and allow the animals to digest the feed more easily. Changing the feed, genetically changing the animal, or changing rumen bacteria in the process can improve the digestibility of livestock feed. Improvement of digestibility leads to better feed efficiency since more food is digested and less waste is produced. Feed enzymes can be used that lead to lower levels of excretion of manure, nitrogen, and phosphorous. Better enzymes can allow animals to eat cheaper and harder-to-digest cereals.

Also, genetically engineered food could allow us to grow a wider variety of foods in the Canadian climate. This will involve the development of new crops that are very different from existing native crops. A northern citrus crop would be an example of this concept. Seeking a higher percentage of food produced locally than today would represent a large saving in transportation and refrigeration costs in the long term. Although, the end product may be different to what the consumer is accustomed.

**Biosensors**

The benefits of combining living cells and information or sensing technologies will give humans more applications for biologically based solutions and will also serve in filling in technology barriers towards nanotechnology. Biological sensors, for example, will allow products and materials to better adapt in a changing environment. Bioreceptor molecules such as enzymes, proteins, and antibodies are key features of living systems, being responsible for control, bio-activity and communication in cells and tissues. When

harnessed, these molecules can be used to develop unique sensors with biotechnological, environmental, and food processing applications.

**Designer Organisms**

At a point of near full knowledge of DNA functions biological bricks could be constructed to create designer organisms. Machines with higher memory capacity and processing speeds will allow for research and analysis of whole systems. Large databases and knowledge of interrelational properties could allow us to bio-construct organisms. Full knowledge of molecules to organisms will open up possibilities inconceivable today. (For more information see TFS A-11.)

**Green House Gas (GHG) Management**

*Stabilization*

Stabilization of GHG's can be achieved, in part, through processes that make no net increase to the atmospheric level of existing GHG gases. The theory behind using biomass as a fuel source is one example of this idea. Life cycle analysis helps us in this process by tracing all aspects of production and conversion for a certain product or service. This can determine the sum total of energy, resources, and emissions required to create a unit of something and allows us to quantitatively compare products and processes. Eventually, it will be goal of future factories and manufacturing plants to have a neutral influence on the surrounding environment in certain aspects, GHG's will be one of them. (For more information see TFS A-1.)

*Source Reduction*

Biotechnology can offer many 'end of pipe' solutions as well as process improvements. From an engineering standpoint it would be easier and more reliable to transform large amounts of point source pollutants than smaller, intermittent amounts of non-point source pollutants with conventional technologies. However, biotechnology's versatility may offer elegant solutions to the most difficult set of criteria or constraints. Car tailpipe processing with microorganisms or enzymes could offer pollutant control at good efficiency rates.

Emission cleansing units using biotechnology may be one of the many steps waste gases must go through before they are released. Not only could these units reduce GHG's and other gases but also particulates. There will be biotechnology niches in particular waste management schemes.

*Longer Term Fixation*

Longer-term fixation of GHG's would be one of the best ways to reduce the ambient levels in the atmosphere. This could be done as a spin-off benefit from biologically derived polymers or this can be done strictly through biological processes.

Extending forested areas into marginal land or redeveloping plants to better synthesize biomass represents one approach. Also, stress-tolerant coral reefs could be developed for $CO_2$ ocean storage. Hybrid trees made to process $CO_2$ could service more specific uses in urban areas. Nitrous and nitric oxide ($NO_X$) fixing trees and microorganisms could

also be produced for use in high concentration urban areas. Genetic engineering will make it possible to produce methane-consuming plants through the insertion of microbial genes or the creation of a new plant/microbe interaction. (For more information see TFS A-3.)

**Adaptive Strategies in a Warmer and Drier Climate**

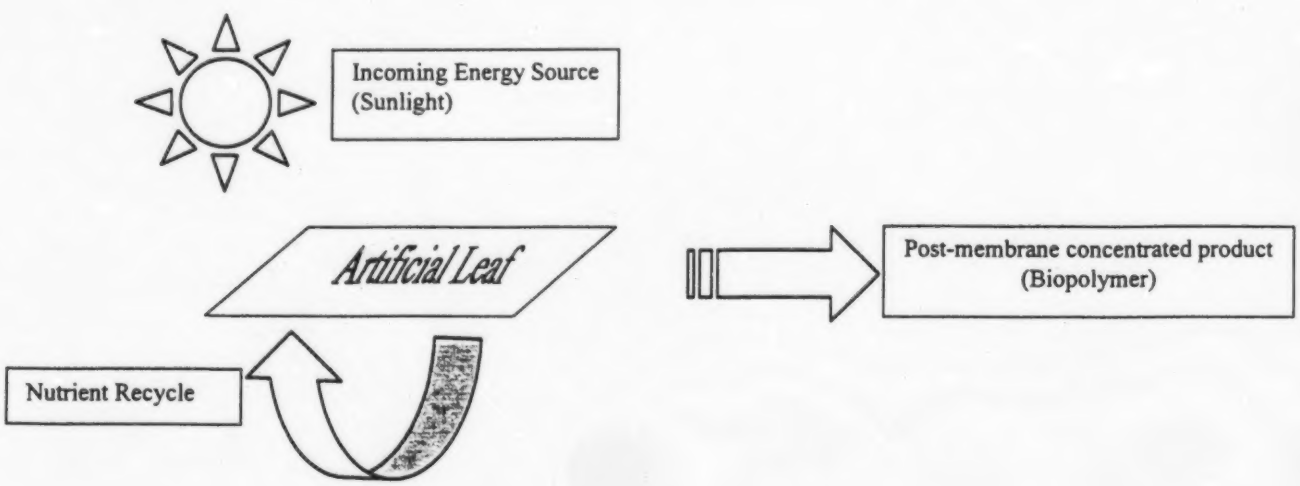
It is clear that the process of climate change has already begun and we must begin to adapt to a changing environment. Crops and trees need to be genetically altered for:

- drought tolerance
- heat tolerance
- higher yields
- faster maturation
- improved nutrient utilization

Also, different agricultural practices such as fall seeding and no-till techniques can improve yields and soil resilience. Continued and improved reforestation efforts through genetic engineering of propagation. This could make mass plantings logistically easier and more likely to take root.

**The Artificial Leaf: An example of a potential application of biotechnology**

One of the ultimate ways of combining biological systems with single-minded functionality of mechanical systems is through artificially designed naturally based tools. For example, if we could design an artificial material that captured light energy and transformed it into chemical reactions using a human-made chlorophyll, the maximum amount of energy available would be diverted to make an engineered final product. Hundreds of square meters of artificial leaves could make biopolymers, for example. The product would be transported from the leaf using a nutrient / solvent and be separated via a membrane to a recycle stream and a high concentration biopolymer vat. Then, the macromolecules could be used in a more mechanical process where it could be molded products.



Technologies required to produce this biological factory would be artificial chlorophyll for the leaf, material advances such as self mending and perhaps growing medium, and a protective covering to stabilize and filter the light. If the materials could repair themselves it would represent a large savings in maintenance. The reaction above could be used for biopolymers or any other macromolecule like ATP as a bio-energy source.

Fuels used in the future by biological systems will be effected by ease of biological creation and usage. These may include:

- Methane
- Hydrogen
- Ethanol
- ATP, starches, and sugars

Industrial uses of biotechnology will mean a large economy based on microorganism and enzyme culturing. Biomass used to create biodegradable plastics, bio-polymers, and bio-fibres. Even perhaps the creation of bio-composites and artificial leaf technology may be viable in the next century.

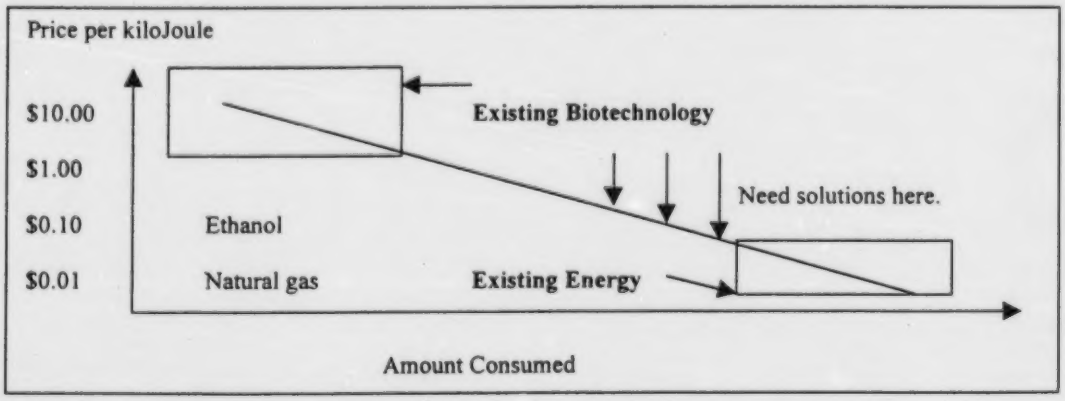
## *Impacts on the Future Energy System*

**Background**

We have many opportunities to explore in the field of biofuels and other biologically derived fuels. However, cheap natural gas and bitumen will be available for the long-term so clean hydrocarbon technologies are niches that also need to be filled.

The energy infrastructure is designed to last for greater than 30 years and in reality it can be used for much longer. New technologies enter through replacement and growth in the energy system. The consequence of this is that historically, only incremental changes occur in the energy supply.

One of the challenges of biotechnology solutions is to commercialize the technologies such that they are competitive with existing technologies. The following graph (not to scale) gives an approximation of where existing biotechnology fuel solutions are located and where they need to be for commercial success. This basic tenant of economics should not be discounted. In the end, the best solution will be affordable, although government regulations and taxes have an ability to move a particular technology along the curve. This leads to the role of government in making alternatives affordable to the public and how the public's demand for an alternative could overtime decrease its price.




**Modes of Energy and Production**

Biotechnology will have a great influence over the development of biologically based fuels, oils, and their feedstocks. Also, there will be other advances in hydrogen and electricity production.

*Biofuels*

There are many opportunities for biologically based fuels and fuel byproducts. Biofuels can be used to supplement existing fossil fuel production. Ethanol is already being sold as an additive in gasoline today. Biogas derived from anaerobic digestion of wastes and biodiesel are other components that could be added to existing fuels. The amount of biomass needed to fuel the entire economy would be enormous. There will be limits to

what we can do with biomass; it will be able to fulfill approximately 25% of fuel needs. When producing biomass there is also an opportunity cost between growing food crops.

Agricultural feedstocks could be tailored to create better niche products for biofuels. Propagation of plants in marginal environments (J. Artichoke or Hybrid Poplars) could become additional feedstock. By enhancing yield of starch or inulin or genetically engineering the plants to be easily fermentable the fuel value per unit of biomass would increase. This would involve producing an easily degradable lignin among other things. Also, more efficient ways of processing ligno-cellulosic wastes by simultaneously saccharifying and fermenting is a possible option. Genetically engineered microbes possibly in a mini, customized ecosystem may be able to perform this task. (For more information see TFS A-5, A-9, and A-10.)

Furthermore, biodegradable waste could also be treated at high temperatures to create synthesis gas through a process of pyrolysis or destructive distillation. Input to pyrolysis processes involve agricultural, municipal solid waste, pulp and paper wastes, and other sources. The organic waste is heated in the absence of oxygen and is broken up into a combustible gas. Since there is no oxygen the reaction is highly endothermic and results in thermal cracking and condensation reactions. The output has three physical phases gaseous, liquid, and solid. The solid phase is a char consisting mostly of carbon and other inert material. The liquid phase consists of tar, oil, acetic acid, acetone, methanol, and oxygenated hydrocarbons. With additional processing this can become a usable fuel oil substitute. The gaseous phase is synthesis gas consisting of carbon monoxide, carbon dioxide, and hydrogen. It can be further purified and burned or processed into ethanol or even bio-converted into methanol.

Also, byproducts of biofuel creation can be sold as commodities in niche markets. Examples of the byproducts are:

- Bio lubricants
- Bio solvents
- Bio polymers
- Bio surfactants and emulsifiers

*Hydrogen Production*

There are many biotechnological methods for hydrogen gas production. Algae and other microorganisms could be used to produce hydrogen either directly or indirectly. It can be done while fixing nitrogen or by processing methanol. Currently, there has been little commercialization of this technology. It will be very much affected by how the energy economy is structured in the future and the technology available for storage and transport. (For more information see TFS A-6 and A-7.)

*Solar*

When it comes to solar power, Canada is a country with a low mean incoming average of energy but a high area of contact. One the most versatile uses for this incoming energy via radiation is biomass production. It is still debatable as to the overall effect solar

power can have in Canada's future energy economy. Where biomass creation is not possible, like in the far north, niche applications of photovoltaics are viable. Below the tree line, economic and physical criteria will determine whether photovoltaics or biomass energy capture is the best option.

**Energy Storage**

Biotechnological ways to help store energy will also be in use in the 2030 – 2050 range. Enzymes tolerant of their harsh environments could aid wet battery storage. The enzymes would allow for better current movement and chemical bonding within the battery. Biochemical engineered energy storage enzymes may also be helpful in hydrogen storage.

H2 + X carrier (aqueous enzymes)→ Storage → H2 (enabling and safe)

Portable hydrogen gas producers would allow generation where it is needed for safety and integrate well into a decentralized energy system. Other methods of energy storage are through exothermic and endothermic reactions. Also, instead of using phase change materials, microbial ecosystems could be used to store heat through chemical reactions.

**Energy Use and Savings**

Since biotechnology is a cross-cutting technology many aspects of it will flow into other industries. Housing may see self-contained homes with biological air purification and the use of biological materials (besides wood) and insulation. Full biological processing of building air may eliminate the need for outside air input and thereby, increase building efficiency. Also, bioluminescence may become a preferred method of lighting for home and streets.

Biological rating methods like life cycle analysis with 'cradle to grave' considerations could be used for many other production decisions and will give us compass to achieve sustainable development. Products could be produced to be more recyclable and become predestined for another use. A new waste management chain can be produced for recycle and recapture for other uses or value-added products. Fossil fuel processing could be enhanced to minimize emissions. Hybrid processes may be developed to bio-upgrade and bio-refine many crude products of today. The addition of bioprocessing techniques throughout manufacturing will give the entire economy greater energy efficiency. As a more cyclical resource usage pattern is adopted, a lot of environmental problems will be more easily solved through this principle shift.

## Preparing Canada for Biotechnology Opportunities 2030-2050

### Canada's Challenges and Opportunities

Canada has a particular outlook as we approach the end of the 20th century. Due to our past history in science and industry and geographical uniqueness, we have certain strengths on which to build and weaknesses to amend.

Our environmental advantages

- Large land mass (most of it sparsely populated)
- Abundant stores of fresh surface water
- Diverse cold weather biosphere
- High standard of living

Our scientific/economic advantages

- Highly developed exports/imports of carbohydrates, oil, and vegetables
- Advanced in natural resource harvesting and processing
- Agricultural biotechnology (particularly oil seeds)
- Information technology

Canada has a great opportunity to sequester carbon in biomass due to the large size of the land mass and low concentration of energy. We can also use cold climate organisms to develop biotech niches using their DNA. This can be done while further developing our strength in oilseeds and agricultural products and using information gained there in other areas. Optimally we will be using Canadian technology to upgrade Canadian resources.

### Research Priorities for Canada

The tools and methods that will be used in the future will evolve regardless of Canada's plan. However, we will be the best position if we act now. For example, genomic efforts are moving very fast throughout the world. After the genome mapping process is completed we may have limited access to information and our own scientists could be restricted. To avoid this we must build a large knowledge base through basic and applied research and set goals to get to certain technologies.

One of the most significant areas underpinning biological research is genome work. This includes mapping, determining the minimum number of genes required for life, and recombinant DNA techniques.

Once we have a better understanding of genes we will be able to develop specific microorganisms and enzymes. In this field there are several areas that need to be explored.

1) **Metabolic process research:** There is a lack of understanding of metabolic processes within microbes. Frequently, large amounts of water are needed in maintaining biological processes. If we can better understand how microbes process material, we can design more efficient strains.

2) **Biocatalysts:** A quantum leap in biocatalysts is required so they can become more useful in a wider range of environments. Most biocatalysts cannot handle the extreme conditions of temperatures, pH, salinity, or pressure of industrial processes. Existing biocatalysts, which are microbial enzyme secretions, can be improved by further knowledge of extremophilic and other processes. Once these are well understood the traits could even be enhanced.

3) **Microbial ecology:** Wider exploration of biological systems, enzymes, cells organisms, microorganisms working in union. Currently biological solutions usually involve one specific kind of organism or enzyme. For the most part, only by accident do they involve more complex inter-organism processes. If we could expand our knowledge of microbial ecology we could engineer diverse communities of life to fulfill processes in a more efficient and less step-intensive way.

4) **New plants:** Identification or creation of new crops for biomass production. This includes all plants grown and harvested from trees to wheat. Creating new strains to produce chemicals, fibres, cellulose, or food. Modifications can be made to allow plants to flourish in a changing atmosphere with less water and human intervention.

5) **Macromolecule creation:** New methods for biological design of molecules and genes (Artificial Plant). This could involve molecular farms creating products from plants, algae, or microbes. They could create biopolymers, proteins, nucleotides, or chemical compounds with high amounts of stored energy.

6) **Mapping Canadian genetic species:** Taking advantage of native species in the local environment to help us manage local forestry, agriculture, etc. Also, northern climate (cold temperature) traits could be used in industrial or chemical synthesis processes.

The previous areas of study could lead to specific projects involving…

7) **Biological methods in engineering:** Including process intensification, measurement, monitoring, and control systems and using biotechnology with other sciences to create novel applications, i.e. computer technology and others. Large-scale utilization of biotechnological solutions would make them more accessible to businesses as well as take away risk and pay for further development of technologies.

8) **Biological purification of natural gas**: This involves removal of the contaminant hydrogen sulphide from the natural gas before it is distributed. If bioprocessing a steady stream of natural gas could do this then the energy savings would be significant. Also, the microbes could render the sulphur into an easily transportable and usable form.

9) **Better breakdown of biomass for ethanol:** If we can improve fermentation techniques for ethanol creation we could produce a better quality ethanol from a wider variety of sources. This involves changing the initial feedstock of fermentation or adjusting microbes and their reactions in the fermentation process.

10) **Using algae and microorganisms as biosensors:** Research involves the development of methods to control the response kinetics of the bioreceptor molecules, methods to chemically amplify these signals, and methods to find polypeptides with binding characteristics similar to those of natural bioreceptors.

11) **Production of hydrogen:** Hydrogen and other fuels could be produced using microbes or low temperature algae on a large scale.

12) **Biological materials:** Home insulation could be cultured inside walls. Artificially intelligent in materials combined with, or composed of, smart bio-materials. Biotechnology could be used to create self-mending and growing machines.

**Factors for Success**

**Links**

There is a tendency within many areas to work independently. It is important and beneficial to all research and engineering groups to have contact with different organizations to share ideas, eliminate duplication, and form partnerships. This refers to all government departments and ministries and academic and research organizations. Many long-term projects require multi-disciplinary efforts so established linkages could help expedite processes. Such efforts will also give actions a strong backing and push solutions into the private and public sector. For example, in Saskatoon, SK, a biotechnology-centered base has developed with the National Research Council, the University of Saskatoon, and Innovation place, a large business park specializing in biotechnology. This concentration of government, business, and academia has made the city a leader in cutting edge research, services, and products. This center of excellence design has also been repeated in other cities like Guelph, ON with the food science industry. Perhaps this model should be pursued in other Canadian cities by encouraging them to match up with complimentary sciences.

**As a Nation**

For Canada to succeed in the next century we must establish a better local base of technology development. This not only includes research and development of technologies but also local commercialization as well. Due to the nature of the world economy it would be necessary for Canadian-based transnationals to assist the public in this venture. Long-term government funding is also required in basic research. This could involve shared databases and performance monitoring. Future biotechnology also requires a very intelligent and educated workforce. Education with a good basic biological understanding for all with continued support in advanced biological sciences would be very important.

It would be optimal to have a balanced technology trade between other nations and ourselves. Canadian control of these exports would be necessary for this to be successful. If we can hold on to more of the technology created here then we would achieve the fundamental objective of upgrading Canadian resources with Canadian technology.

Government has been successful in this regard when it comes to crop biotechnology by supporting key enterprises in key areas to become international leaders. The idea of concentrating highly skilled people geographically has been successful in the case of the Plant Biotechnology Institute. A mix of government, academic, and industrial efforts has created a world class centre of expertise.

Canada does not necessarily need to be at the cutting edge of a technology initially to be a world leader in its application. For example, information technology was not developed in Canada but we have adopted the technology and it has become a significant export. However, our basic sovereignty over our own genetic inheritance (biosphere and citizens) should be claimed. This type of forward-looking proactive legislation would help prevent Canadian capital being undermined in the early stages of this technology.

**Public Perception and Policy**

To increase our stake in biotechnology Canada must handle policy decisions with sound knowledge and a supportive public. Knowledge as scientific information must move towards public information and understanding. Public policy and relations should assist the public in understanding biotechnology and provide leadership in regulations to show support and to respond to the public's wariness about possible applications. Confidence in regulatory systems could be key to public acceptance.

## Conclusions and Questions

### Conclusions

Biotechnology is at the beginning of an exponential curve that will advance that science to many technological ends. Hurdles such as element cycles, water dependency, and other knowledge gaps will be eventually crossed. There are technologies that deal with all forms of life and which may have many end uses. Canada can not specialize in everything so perhaps we should try to choose niches now. Natural Canadian strengths lie in forestry, mining, petroleum, agriculture, and information technology. These are excellent starting points but they do not need to bind us.

As the age of industrialization my be characterized by conformity and standardization, the age of biotechnology and information science will give society a wide range of applications designed for many new specific functions with overtones of both diversity and integration. These patterns will also be incorporated into our scientific methods like life cycle analysis, DNA computing and problem solving and better modeling techniques.

### Key Questions

As the focus group progressed during the day we learned more about biotechnology but we also were able to ask better questions. Here is a list of a few questions that still need to be answered.

Will we have to curtail meat production to meet biomass needs?
How well does a large area and a low concentration lend itself to solar power usage?
To what extent should biomass be created on Canadian land?
**Please feel free to add more...**

## Glossary of Terms

**Adaptive radiation**
The evolution of new species or sub-species to fill unoccupied ecological niches.

**Aerobe**
A microorganism that grows in the presence of oxygen. See Anaerobe.

**Alternative mRNA splicing**
The inclusion or exclusion of different exons to form different mRNA transcripts. (See RNA.)

**Amino acid**
Any of 20 basic building blocks of proteins-- composed of a free amino ($NH_2$) end, a free carboxyl (COOH) end, and a side group (R). A protein is composed of a chain of hundreds or thousands of amino acids. However, eight amino acids (called "essential amino acids") must be obtained from food.

**Amplify**
To increase the number of copies of a DNA sequence, in vivo by inserting into a cloning vector that replicates within a host cell, or in vitro by polymerase chain reaction (PCR).

**Anaerobe**
An organism that grows in the absence of oxygen. See Aerobe.

**Antimicrobial agent**
Any chemical or biological agent that harms the growth of microorganisms.

**ATP (Adenosine Tri-Phosphate)**
The principle energy carrier for a cell. Energy from oxidation-reduction reactions is stored in phosphate bonds used to drive biosynthetic reactions.

**Autosome**
A chromosome that is not involved in sex determination.

**beta-DNA**
The normal form of DNA found in biological systems, which exists as a right-handed helix.

**Bacterium**
A single-celled, microscopic prokaryotic organism: a single cell organism without a distinct nucleus.

**Base pair (bp)**
A pair of complementary nitrogenous bases in a DNA molecule, adenine-thymine and guanine-cytosine. Also, the unit of measurement for DNA sequences.

**Biocatalyst**
An enzyme that activates or speeds up a chemical reaction.

**Biodiversity**
The wide diversity and interrelations of earth organisms based on genetic and environmental factors.

**Bioenrichment**
Adding nutrients or oxygen to increase microbial breakdown of pollutants.

**Biofilms**
See Microbial mats.

**Biological control**
The use of one organism to control the population size of another organism.

**Biological molecules**
Large, complex molecules, such as proteins, nucleic acids, lipids and carbohydrates, that are produced only by living organisms. Biological molecules are often referred to as macromolecules or biopolymers.

**Biomass**
The total dry weight of all organisms in a particular sample, population, or area.

**Bioprocessing**
A technique in which microorganisms, living cells, or their components are used to produce a desired end product.

**Bioreactor**
A container used for bioprocessing.

**Bioremediation**
The use of organisms, usually microorganisms, to break down pollutants in soil, air or groundwater.

**Biosensor technology**
The use of cells or biological molecules in an electronic system to detect specific substances. Consists of a biological sensing agent coupled with a microelectronic circuit.

**Biosynthesis**
Production of a chemical by a living organism.

**Biotechnology**
A collection of technologies that use manipulation of living cells and/or biological molecules, especially at the genetic level, to solve problems and make useful products.

**Catalyst**
A substance that promotes a chemical reaction by lowering the activation energy of a chemical reaction, but which itself remains unaltered at the end of the reaction.

**Centers of origin**
Usually the location in the world where the oldest cultivation of a particular crop has been identified.

**Cell**
The smallest structural unit of living organisms that is able to grow and reproduce independently.

**Cellulose**
A linear polymer of glucose that surround plant and algal cell walls.

**Chromosome**
A single DNA molecule, a tightly coiled strand of DNA, condensed into a compact structure in vivo by complexing with accessory histones or histone-like proteins. Chromosomes exist in pairs in higher eukaryotes: one obtained from the mother; the other from the father.

**Clone**
An exact genetic replica of a specific gene or an entire organism. Clones are produced from a single parent cell. See Cloning.

**Cloning**
The mitotic division of a progenitor cell to give rise to a population of identical daughter cells or clones.

**Colony**
A group of identical cells (clones) derived from a single initial cell.

**Cross-hybridization**
The hydrogen bonding of a single- stranded DNA sequence that is partially but not entirely complementary to a single stranded substrate. Often, this involves hybridizing a DNA probe for a specific DNA sequence to the homologous sequences of different species.
**Cross-pollination**
Fertilization of a plant from a plant with a different genetic makeup.
**Culture**
A particular kind of organism growing in a laboratory medium or media.
**Culture medium**
A nutrient system for artificially growing bacteria or other cells.
**DNA (Deoxyribonucleic acid)**
An organic acid and polymer composed of four nitrogenous bases, adenine, thymine, cytosine, and guanine linked via intervening units of phosphate and the pentose sugar deoxyribose. DNA is the genetic material of most organisms and usually exists as a double-stranded molecule in which two antiparallel strands are held together by hydrogen bonds between adeninethymine and cytosine-guanine. DNA belongs to a class of biological molecules called nucleic acids.
**DNA sequencing**
The order of nucleotide bases in the DNA molecule or procedures for determining the nucleotide sequence of a DNA fragment.
**Dormancy**
A period in which a plant does not grow, awaiting necessary environmental conditions such as temperature, moisture, nutrient availability.
**Double helix**
Describes the coiling of the antiparallel strands of the DNA molecule, resembling a spiral staircase in which the paired bases form the steps and the sugar-phosphate backbones form the rails.
**Ecology**
The study of the interactions of organisms with their environment and with each other.
**Ecosystem**
The organisms in a plant population and the factors which impact on them.
**Electroporation**
A method for transforming DNA, especially useful for plant cells, in which high voltage pulses of electricity are used to open pores in cell membranes, through which foreign DNA can pass.
**Enzymes**
Proteins that control the various steps in all chemical reactions. Enzymes are catalysts that promote reactions repeatedly, without being damaged by the reactions.
**Escherichia coli (E. coli)**
A bacterium inhabiting the human colon that is widely used in biology, both as a simple model of cell biochemical function and as a host for molecular cloning experiments.
**Eukaryote**
An organism whose cells possess a nucleus and other membrane-bound vesicles, including all members of the protist, fungi, plant and animal kingdoms; and excluding viruses, bacteria, and blue-green algae. See Prokaryote.

**Evolution**
The long-term process through which a population of organisms accumulates genetic changes that enable its members to successfully adapt to environmental conditions and to better exploit food resources.
**Expression**
The physical manifestation of the information contained in a gene.
**Extremophile**
Any organism that tolerates or requires extreme aspects in the environment such as pressure, salinity, pH, heat, cold, radioactivity or dehydration.
**Fermentation**
A process of growing microorganisms to produce various chemical or pharmaceutical compounds. Microbes are usually incubated under specific conditions in large tanks called fermentors. Fermentation is a specific type of bioprocessing.
**Fungicide**
An agent, such as a chemical, that kills fungi.
**Fungus**
A microorganism that lacks chlorophyll.
**Fusion gene**
A hybrid gene created by joining portions of two different genes (to produce a new protein) or by joining a gene to a different promoter (to alter or regulate gene transcription).
**GEM**
A genetically engineered microorganism.
**Gene**
A locus on a chromosome that encodes a specific protein or several related proteins. It is considered the functional unit of heredity. A gene is a section of a DNA molecule that specifies the production of a particular protein.
**Gene amplification**
The presence multiple copies of genetic information in a cell.
**Gene cloning**
The process of synthesizing multiple copies of a particular DNA sequence using a bacteria cell or another organism as a host. See DNA, Host.
**Gene expression**
The process of producing a protein from its DNA- and mRNA-coding sequences.
**Gene insertion**
The addition of one or more copies of a normal gene into a defective chromosome.
**Gene mapping**
Determining the relative locations of genes on a chromosome.
**Gene pool**
The totality of all genes of all individuals in a particular population.
**Gene splicing**
Combining genes from different organisms into one organism. See recombinant DNA.
**Gene translocation**
The movement of a gene fragment from one chromosomal location to another, which often alters or abolishes expression.

**Genetic assimilation**
Eventual extinction of a natural species as massive pollen flow occurs from another related species and the older crop becomes more like the new crop. See Gene flow.
**Genetic code**
The three-letter code that translates nucleic acid sequence into protein sequence. The relationships between the nucleotide base-pair triplets of a messenger RNA molecule and the 20 amino acids that are the building blocks of proteins.
**Genetic engineering**
The manipulation of an organism's genetic endowment by introducing or eliminating specific genes through modern molecular biology techniques. A broad definition of genetic engineering also includes selective breeding and other means of artificial selection.
**Genome**
The genetic complement contained in the chromosomes of a given organism.
**Genomic library**
A library composed of fragments of genomic DNA. (See Library.)
**Genotype**
The structure of DNA that determines the expression of a trait. See Phenotype.
**Genus**
A category including closely related species. Interbreeding between organisms within the same category can occur.
**GEO**
Genetically engineered organism.
**GMO**
Genetically modified organism.
**Green revolution**
Advances in genetics, petrochemicals, and machinery that culminated in a dramatic increase in crop productivity during the third quarter of the 20th century.
**Growth phase (curve)**
The characteristic periods in the growth of a bacterial culture, as indicated by the shape of a graph of viable cell number versus time. (See Death phase, Lag phase, Logarithmic phase, Stationary phase.)
**Herbicide**
Any substance that is toxic to plants; usually used to kill specific unwanted plants.
**Host**
An organism that contains another organism.
**Human Genome Project**
A project coordinated by the National Institutes of Health (NIH) and the Department of Energy (DOE) to determine the entire nucleotide sequence of the human chromosomes.
**Hybrid**
The offspring of two parents differing in at least one genetic characteristic (trait).
**Hybridization**
Production of offspring, or hybrids, from genetically dissimilar parents. In selective breeding, it usually refers to the offspring of two different species.

**Hydrogen bond**
A relatively weak bond formed between a hydrogen atom (which is covalently bound to a nitrogen or oxygen atom) and a nitrogen or oxygen with an unshared electron pair.
**Hydrolysis**
A reaction in which a molecule of water is added at the site of cleavage of a molecule to two products.
**In silico**
Performed through computer modelling???
**In situ**
Refers to performing assays or manipulations with intact tissues.
**In vitro**
Performed in a test tube or other laboratory apparatus.
**In vivo**
Refers to biological processes that take place within a living organism or cell.
**In vitro selection**
Selection at the cellular or callus stage of individuals possessing certain traits, such as herbicide resistance.
**Insertion mutations**
Changes in the base sequence of a DNA molecule resulting from the random integration of DNA from another source. See DNA, Mutation.
**Invasiveness**
Ability of a plant to spread beyond its introduction site and become established in new locations where it may provide a deliterious effect on organisms already existing there.
**Ion**
A charged particle.
**Isotope**
One of two or more forms of an element that have the same number of protons (atomic number) but differing numbers of neutrons (mass numbers). Radioactive isotopes are commonly used to make DNA probes and metabolic tracers.
**Lag phase**
The initial growth phase, during which cell number remains relatively constant prior to rapid growth.
**Legume**
A member of the pea family that possesses root nodules containing nitrogen-fixing bacteria.
**Library**
A collection of cells, usually bacteria or yeast, that have been transformed with recombinant vectors carrying DNA inserts from a single species.
**Lignin**
A complex aromatic polymer and a major component of wood, responsible for conferring rigidity on the cellulosic walls of woody plants. Resistant to anaerobic degradation.
**Logarithmic phase (log or exponential growth phase)**
The steepest slope of the growth curve--the phase of vigorous growth during which cell number doubles every 20-30 minutes. (See Growth phase.)
**Lysis**
The destruction of the cell membrane.

**Mapping**
Determining the physical location of a gene or genetic marker on a chromosome. (See Continuous map, Genetic map, Physical map.)
**Metabolism**
The biochemical processes that sustain a living cell or organism.
**Metabolite**
Compounds produced through a culture's life cycle. Metabolites can be separated into primary metabolites (compounds produced during the primary growth phase) and secondary metabolites (produced during the stationary
**Microbe**
A microorganism.
**Microbial mats (biofilms)**
Layered groups or communities of microbial populations.
**Microinjection**
A means to introduce a solution of DNA, protein, or other soluble material into a cell using a fine microcapillary pipet.
**Mitosis**
The replication of a cell to form two daughter cells with identical sets of chromosomes.
**Molecular biology**
The study of the biochemical and mo- lecular interactions within living cells.
**Molecular cloning**
The biological amplification of a specific DNA sequence through mitotic division of a host cell into which it has been transformed or transfected. (See Cloning.)
**Molecular genetics**
The study of the flow and regulation of genetic information between DNA, RNA, and protein molecules.
**Monoculture**
The agricultural practice of cultivating crops consisting of genetically similar organisms.
**Mutagen**
Any agent or process that can cause mutations.
**Mutant**
A cell microorganism that manifests new characteristics due to a change in its genetic material.
**Mutation**
An alteration in DNA structure or sequence of a gene.
**Natural selection**
The differential survival and reproduc- tion of organisms with genetic characteristics that enable them to better utilize environmental resources.
**Nitrogen fixation**
The conversion of atmospheric nitrogen to biologically usable nitrates.
**Nodule.** The enlargement or swelling on roots of nitrogen- fixing plants. The nodules contain symbiotic nitrogen- fixing bacteria. See Nitrogen fixation.
**Nucleic acid**
A biological molecule composed of a long chain of nucleotides. DNA is made of thousands of four different nucleotides repeated randomly.

**Nucleotide**
A compound made up of these three components: a sugar, phosphate and a nitrogen-containing base. Found as individual molecules (e.g., ATP, the "energy molecule"), or as many nucleotides linked together in a chain (nucleic acid such as DNA).
**Nucleus**
The membrane-bound region of a eukaryotic cell that contains the chromosomes.
**Paleontology**
The study of the fossil record of past geological periods and of the phylogenetic relationships between ancient and contemporary plant and animal species.
**Persistence**
Ability of an organism to remain in a particular setting for a period of time after it is introduced.
**Pesticide**
A substance that kills harmful organisms (for example, an insecticide or fungicide).
**Plasmid**
A circular DNA molecule, capable of autonomous replication, which typically carries one or more genes encoding antibiotic resistance proteins. Plasmids can transfer genes between bacteria and are important tools of transformation for genetic engineers.
**Polymer**
A molecule composed of repeated subunits.
**Polypeptide (protein)**
A polymer composed of multiple amino acid units linked by peptide bonds.
**Polysaccharide**
A polymer composed of multiple units of monosaccharide (simple sugar).
**Population**
A local group of organisms belonging to the same species and capable of interbreeding.
**Prokaryote**
Organisms whose genetic material is not enclosed by a nucleus. The most common examples are bacteria.
**Primary cell**
A cell or cell line taken directly from a living organism.
**Promoter**
A region of DNA extending 150-300 bp upstream from the transcription start site that contains binding sites for RNA polymerase and a number of proteins that regulate the rate of transcription of the adjacent gene.
**Protein**
A polymer of amino acids linked via peptide bonds and which may be composed of two or more polypeptide chains. The information for making proteins is stored in the sequence of nucleotides in the DNA molecule.
**Protein engineering**
A technique used in the production of proteins with new or artificial amino acid sequences.
**Protoplast**
A plant or bacterial cell that has had its cell wall removed.

**Recessive gene**
Characterized as having a phenotype expressed only when both copies of the gene are mutated or missing.
**Recombinant**
A cell that results from recombination of genes.
**Recombinant DNA**
The process of cutting and recombining DNA fragments from different sources as a means to isolate genes or to alter their structure and function. Humans direct the formation of recombinant DNA through selective breeding and genetic engineering.
**Recombinant DNA (rDNA) technology**
The laboratory manipulation of DNA in which DNA, or fragments of DNA from different sources, are cut and recombined using enzymes. This recombinant DNA is then inserted into a living organism. rDNA technology is usually used synonymously with genetic engineering.
**Recombination**
The formation of new combinations of genes. Recombination occurs naturally in plants and animals during the production of sex cells (sperm, eggs, pollen) and their subsequent joining in fertilization. In microbes, genetic material is recombined naturally during conjugation.
**Regeneration**
The process of growing an entire plant from a single cell or group of cells.
**Regulatory gene**
A gene whose protein controls the activity of other genes or metabolic pathways.
**Restriction enzymes**
Bacterial enzymes that cleave DNA at very specific locations.
**Rhizobia**
Bacteria in a symbiotic relationship with leguminous plants that results in nitrogen fixation. See Nitrogen fixation.
**Rhizosphere**
The soils region on and around plant roots.
**RNA (ribonucleic acid)**
Like DNA, a type of nucleic acid. There are three major types: messenger RNA, transfer RNA, and ribosomal RNA. All are involved in the synthesis of proteins from the information contained in the DNA molecule.
**Rumen Bacteria**
Digestive bacteria that reside in the organ called the rumen in cattle or sheep.
**Self-pollination**
Pollen of one plant is transferred to the female part of the same plant or another plant with the same genetic makeup.
**Sexual reproduction**
The process where two cells (gametes) fuse to form one hybrid, fertilized cell.
**Species**
A classification of related organisms that can freely interbreed.
**Spore**
A form taken by certain microbes that enables them to exist in a dormant stage. It is an asexual reproductive cell. See Asexual reproduction, Dormant.

**Stationary phase**
The plateau of the growth curve after log growth, during which cell number remains constant. New cells are produced at the same rate as older cells die. (See Growth phase.)
**Substrate**
The molecule undergoing reaction with the enzyme.
**Supernatant**
The soluble liquid fraction of a sample after centrifugation or precipitation of insoluble solids.
**Symbiosis**
The close association of two or more dissimilar organisms where both receive an advantage from the association.
**Tissue culture**
A procedure for growing or cloning enough cells through in vitro techniques to make a tissue.
**Transduction**
The transfer of DNA sequences from one bacterium to another via lysogenic infection by a bacteriophage (transducing phage).
**Transfection**
The uptake and expression of a foreign DNA sequence by cultured eukaryotic cells.
**Transformation**
A change in the genetic structure of an organism as a result of the uptake and incorporation of foreign DNA.
**Transformation efficiency**
The number of bacterial cells that uptake and express plasmid DNA divided by the mass of plasmid used (in transformants/microgram).
**Transgenic**
An organism in which a foreign DNA gene (a transgene) is incorporated into its genome early in development. The transgene is present in both somatic and germ cells, is expressed in one or more tissues, and is inherited by offspring in a Mendelian fashion. See Transgenic animal, Transgenic plant.
**Transgenic animal**
Genetically enginnered animal or offspring of genetically engineered animals. The transgenic animal usually contains material from at least one unrelated organism, such as from a virus, plant, or other animal.
**Transgenic plant**
Genetically engineered plant or offspring of genetically engineered plants. The transgenic plant usually contains material from at least one unrelated organisms, such as from a virus, animal, or other plant.
**Variation**
Differences in the frequency of genes and traits among individual organisms within a population.
**Vector**
An autonomously replicating DNA molecule into which foreign DNA fragments are inserted and then propagated in a host cell. Also living carriers of genetic material (such as pollen) from plant to plant, such as insects.

**Virus**
An infectious particle composed of a protein capsule and a nucleic acid core, which is dependent on a host organism for replication. A double-stranded DNA copy of an RNA virus genome that is integrated into the host chromosome during lysogenic infection.
**Wild type**
An organism as found in nature; the organism before it is genetically engineered.

## Afterthoughts

Please add any final comments of the overall report…